



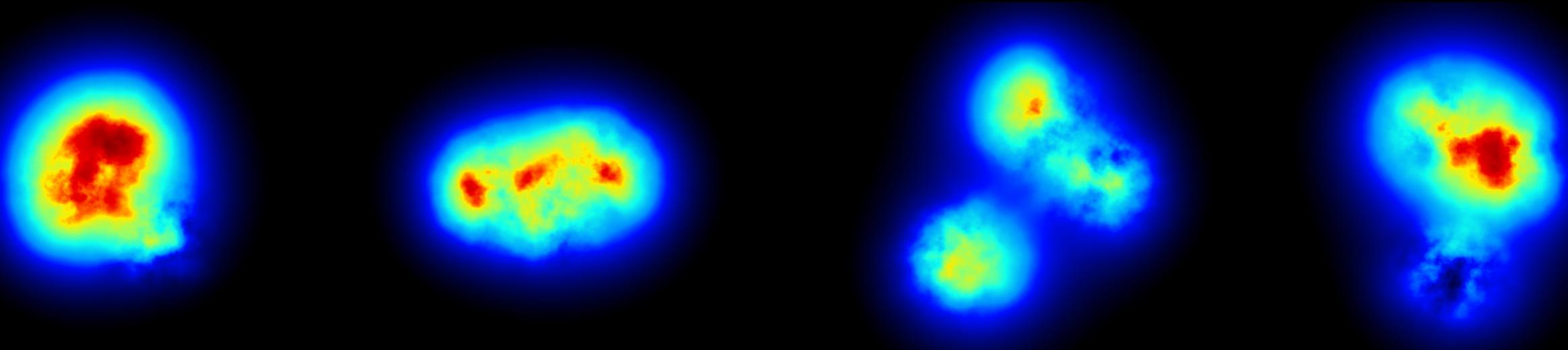
U.S. DEPARTMENT OF
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Science

BROOKHAVEN
NATIONAL LABORATORY

EVIDENCE OF STRONG PROTON SHAPE FLUCTUATIONS FROM INCOHERENT DIFFRACTION

BJÖRN SCHENKE, BROOKHAVEN NATIONAL LABORATORY



November 16, 2016
POETIC 7
Temple University, Philadelphia

FUNDAMENTAL QUESTIONS:

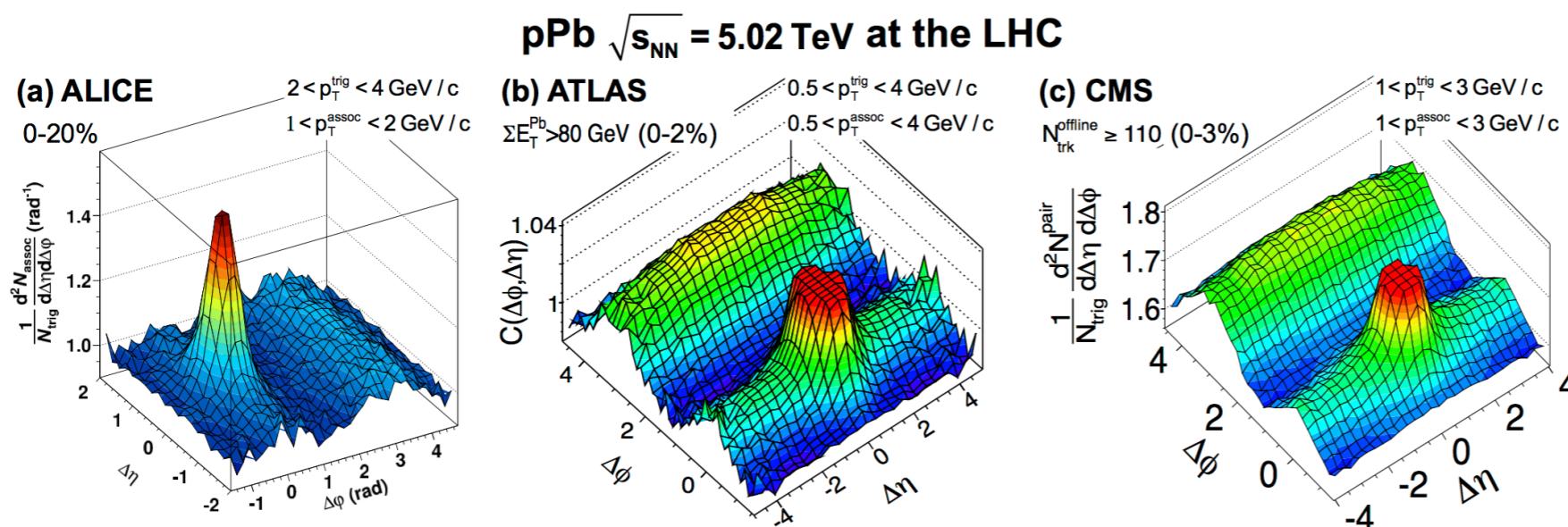
What is the spatial distribution of quarks
and gluons inside the nucleon?

How does this distribution fluctuate?

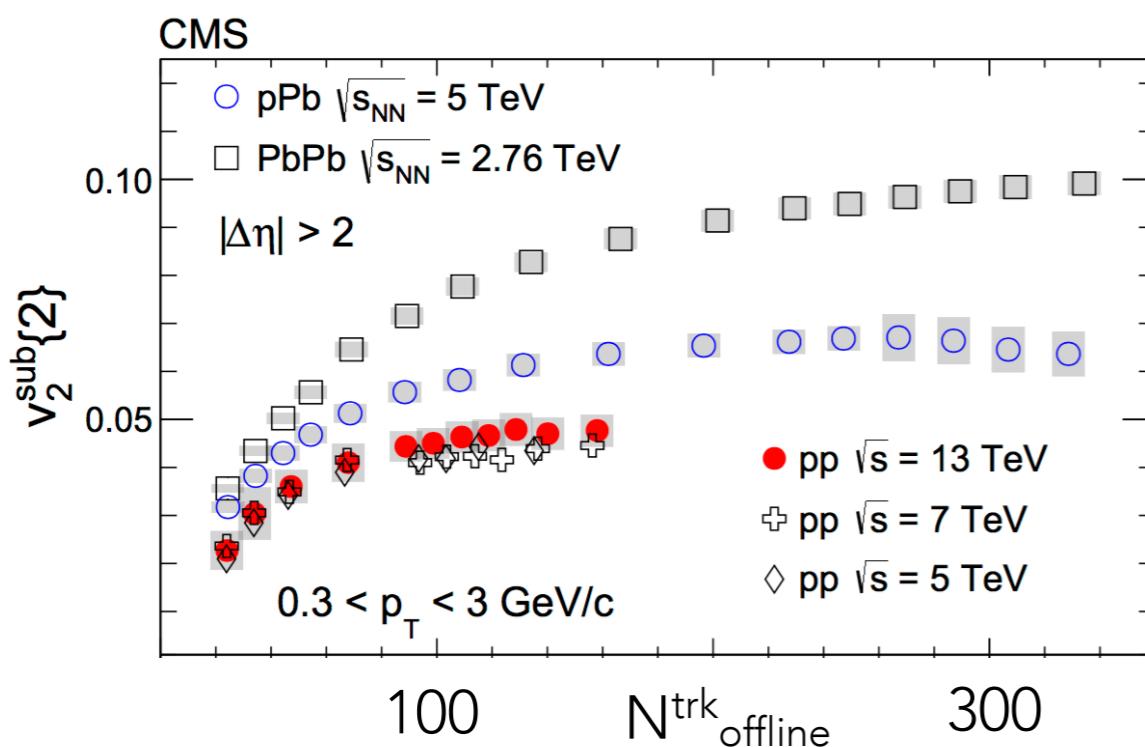
The question is also relevant for
understanding p+A collision

COLLECTIVITY IN p+p, p+Pb COLLISIONS

2-particle correlation as a function of $\Delta\eta$ and $\Delta\phi$

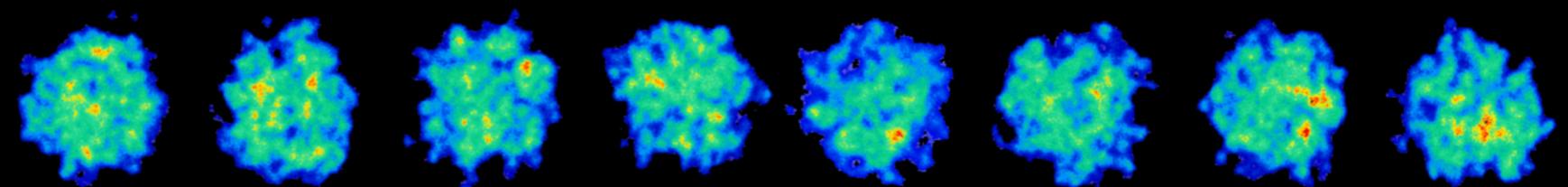


Ridge:
 Long range
 correlation in $\Delta\eta$
 with certain
 structure in $\Delta\phi$



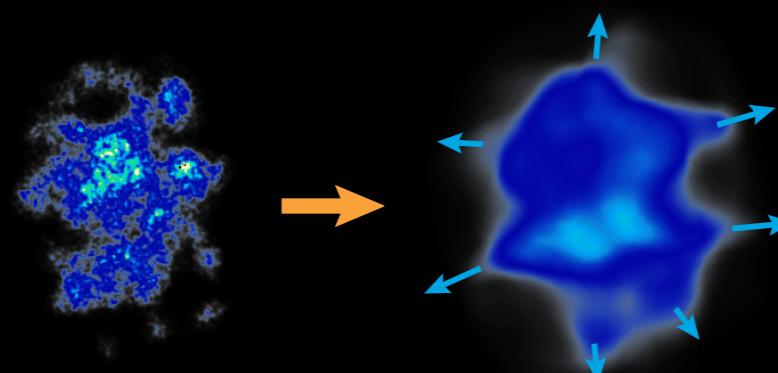
GEOMETRY FLUCTUATIONS

Possible explanation are initial state shape fluctuations that are turned into momentum space correlations by strong final state interactions

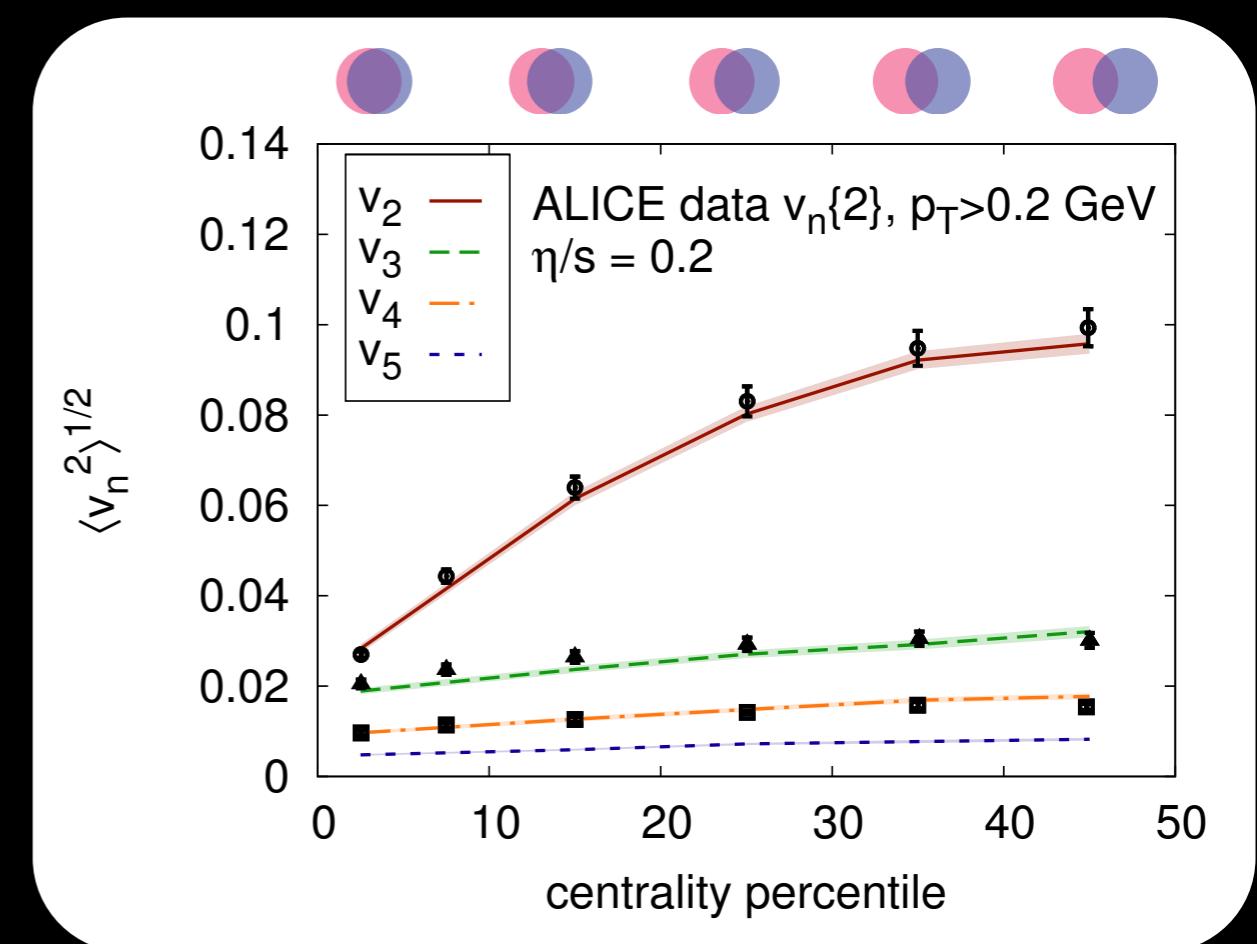


This works in A+A collisions

C. GALE, S. JEON, B. SCHENKE, P. TRIBEDY,
R. VENUGOPALAN, PRL110, 012302 (2013)



using color glass condensate
initial state (IP-Glasma) and
MUSIC viscous hydrodynamics

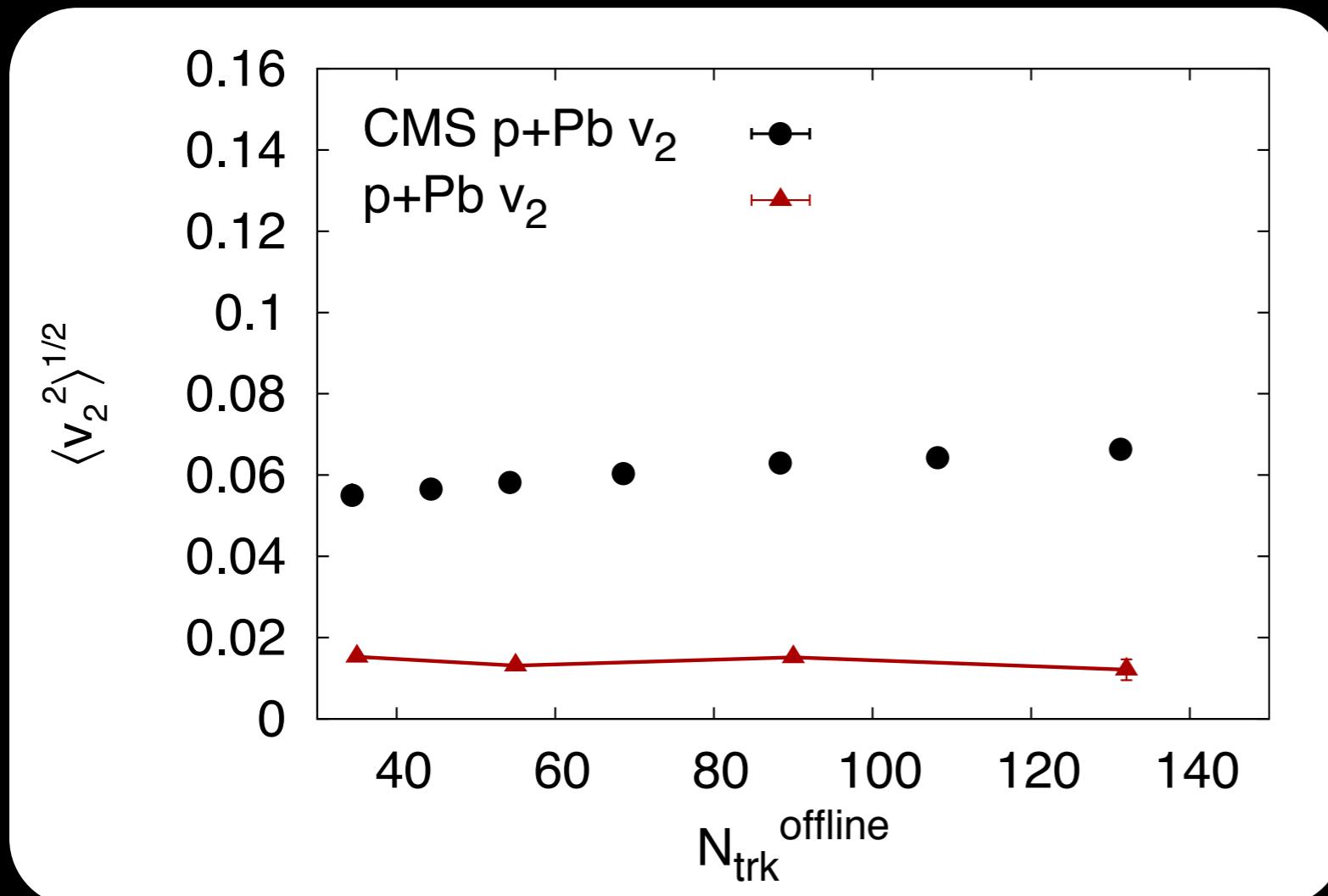


EXP. DATA: ALICE COLLABORATION
PHYS. REV. LETT. 107, 032301 (2011)

STRONG FINAL STATE EFFECTS IN SMALL SYSTEMS? EVEN HYDRODYNAMICS?

B. SCHENKE, R. VENUGOPALAN, PRL113 (2014) 102301

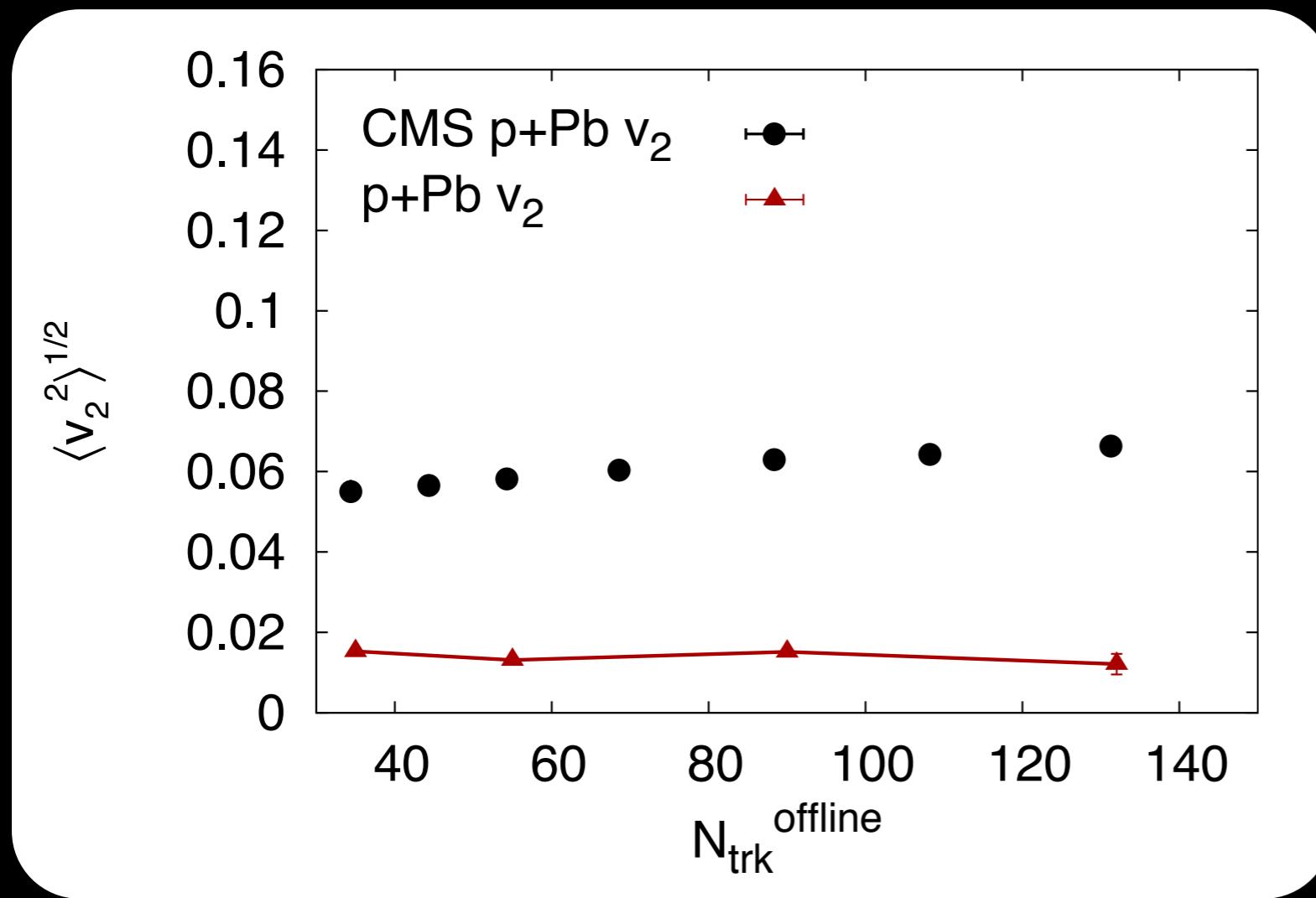
SAME MODEL THAT WORKS WELL IN Pb+Pb FAILS IN p+Pb



STRONG FINAL STATE EFFECTS IN SMALL SYSTEMS? EVEN HYDRODYNAMICS?

B. SCHENKE, R. VENUGOPALAN, PRL113 (2014) 102301

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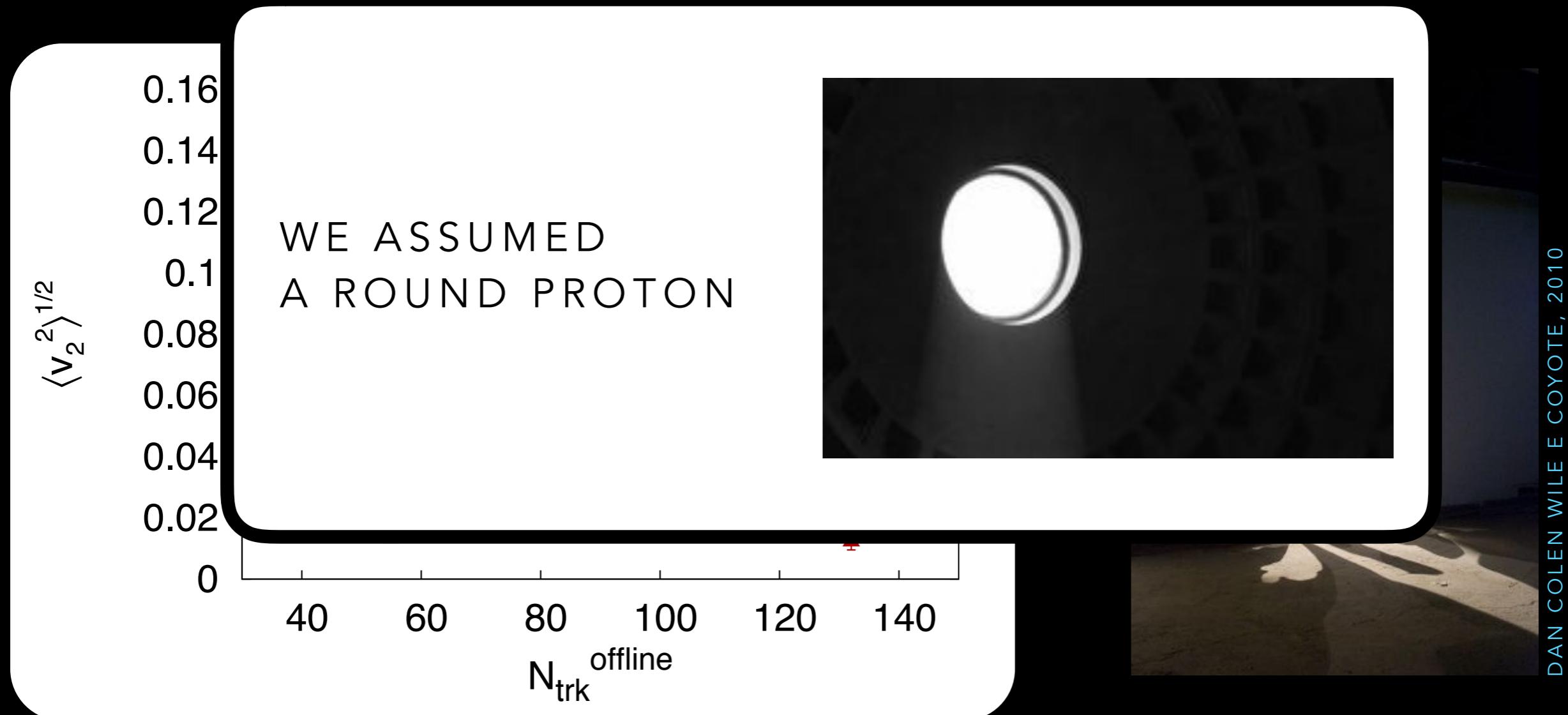
DAN COLENS WILE E COYOTE, 2010

IN THE YANG-MILLS FRAMEWORK SHAPE OF THE SYSTEM
FOLLOWS SHAPE OF THE PROTON
PROTON: WILE E COYOTE; HEAVY ION: WALL

STRONG FINAL STATE EFFECTS IN SMALL SYSTEMS? EVEN HYDRODYNAMICS?

B. SCHENKE, R. VENUGOPALAN, PRL113 (2014) 102301

SAME MODEL THAT WORKS WELL IN Pb+Pb FAILS IN p+Pb



SHAPE OF THE SYSTEM FOLLOWS SHAPE OF THE PROTON
PROTON: WILE E COYOTE
LEAD: WALL

HOW TO CONSTRAIN PROTON SHAPE FLUCTUATIONS?

H. MÄNTYSAARI, B. SCHENKE, PHYS. REV. LETT. 117, 052301 (2016)
AND PHYS. REV. D94, 034042 (2016)

ADDITIONAL DEGREE OF FREEDOM:
PROTON SHAPE FLUCTUATIONS

NEED ADDITIONAL PIECE OF DATA AS
CONSTRAINT IN THE SPIRIT OF THE ORIGINAL
IP-GLASMA MODEL

THIS DATA IS INCOHERENT EXCLUSIVE
DIFFRACTIVE VECTOR MESON PRODUCTION
AT E.G. HERA AND A FUTURE EIC

DIFFRACTIVE J/Ψ PRODUCTION

e+p collisions, no exchange of color charge

Large rapidity gap

Coherent diffraction:

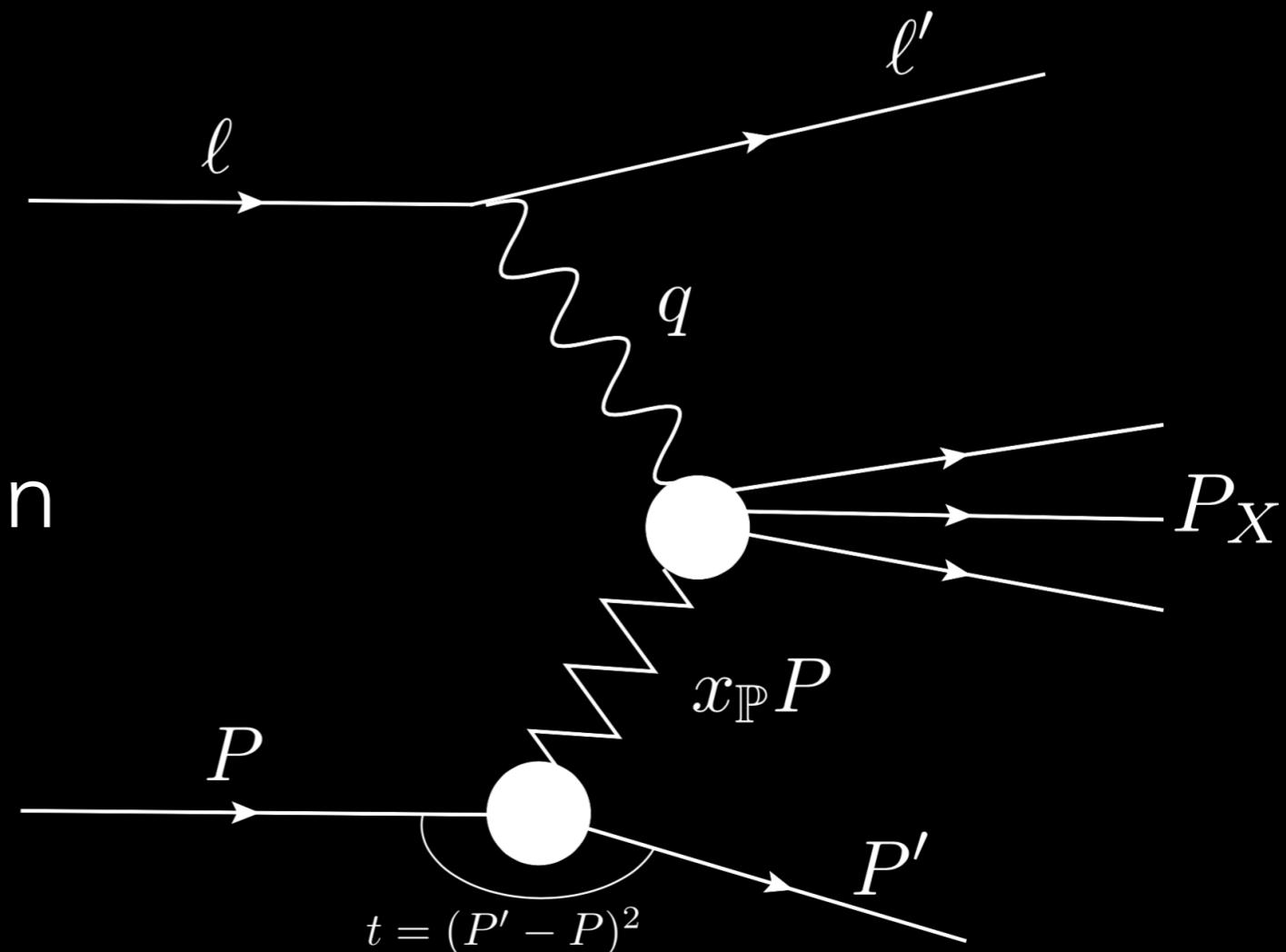
Proton remains intact

Sensitive to average gluon distribution in the proton

Incoherent diffraction:

Proton breaks up

Sensitive to shape fluctuations



CGC FRAMEWORK J/Ψ PRODUCTION

Diffractive eigenstates are color dipoles at fixed r_T and b_T

M. L. GOOD AND W. D. WALKER, PHYS. REV. 120 (1960) 1857

Scattering amplitude:

H. KOWALSKI, L. MOTYKA, G. WATT, PHYS. REV. D74, 074016 (2006)

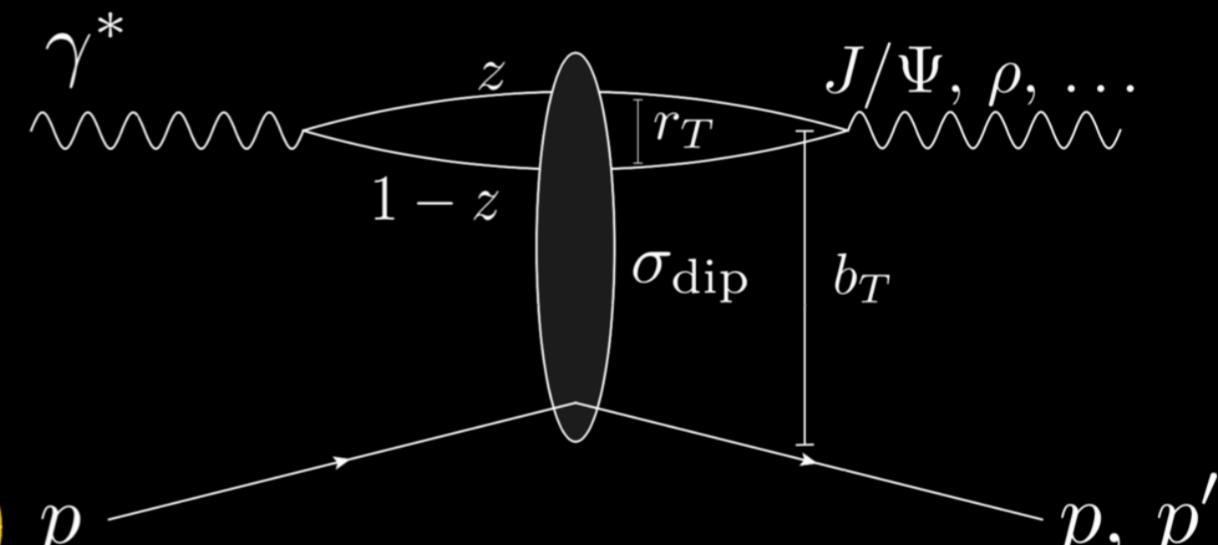
$$\mathcal{A} \sim \int d^2 b dz d^2 r \Psi^* \Psi^V(r, z, Q^2) e^{-ib \cdot \Delta} N(r, x, b)$$

- Ψ^* : Incoming virtual photon fluctuates into a $q - \bar{q}$ dipole

- N : Dipole scatters elastically

$$\sigma_{\text{dip}}(x, r, \Delta) = 2 \int d^2 b e^{ib \cdot \Delta} N(r, x, b) p$$

- Ψ^V : amplitude for quark–antiquark dipole \rightarrow vector meson



Δ : transverse momentum
of vector meson

AVERAGING OVER THE TARGET

H. MÄNTYSAARI, B. SCHENKE, PHYS. REV. LETT. 117, 052301 (2016)
AND PHYS. REV. D94, 034042 (2016)

COHERENT DIFFRACTION:
TARGET STAYS INTACT

$$\frac{d\sigma^{\gamma^* p \rightarrow Vp}}{dt} = \frac{1}{16\pi} \left| \langle \mathcal{A}^{\gamma^* p \rightarrow Vp}(x_{\mathbb{P}}, Q^2, \Delta) \rangle \right|^2$$

INCOHERENT DIFFRACTION:
TARGET BREAKS UP

$$\frac{d\sigma^{\gamma^* p \rightarrow Vp^*}}{dt} = \frac{1}{16\pi} \left(\left\langle \left| \mathcal{A}^{\gamma^* p \rightarrow Vp}(x_{\mathbb{P}}, Q^2, \Delta) \right|^2 \right\rangle - \left| \langle \mathcal{A}^{\gamma^* p \rightarrow Vp}(x_{\mathbb{P}}, Q^2, \Delta) \rangle \right|^2 \right)$$

SENSITIVE TO FLUCTUATIONS!

SEE
H. I. MIETTINEN
AND J. PUMPLIN
PHYS. REV. D18 (1978) 1696

Y. V. KOVCHEGOV
AND L. D. MCLERRAN
PHYS. REV. D60 (1999) 054025

A. KOVNER AND
U. A. WIEDEMANN
PHYS. REV. D64 (2001) 114002

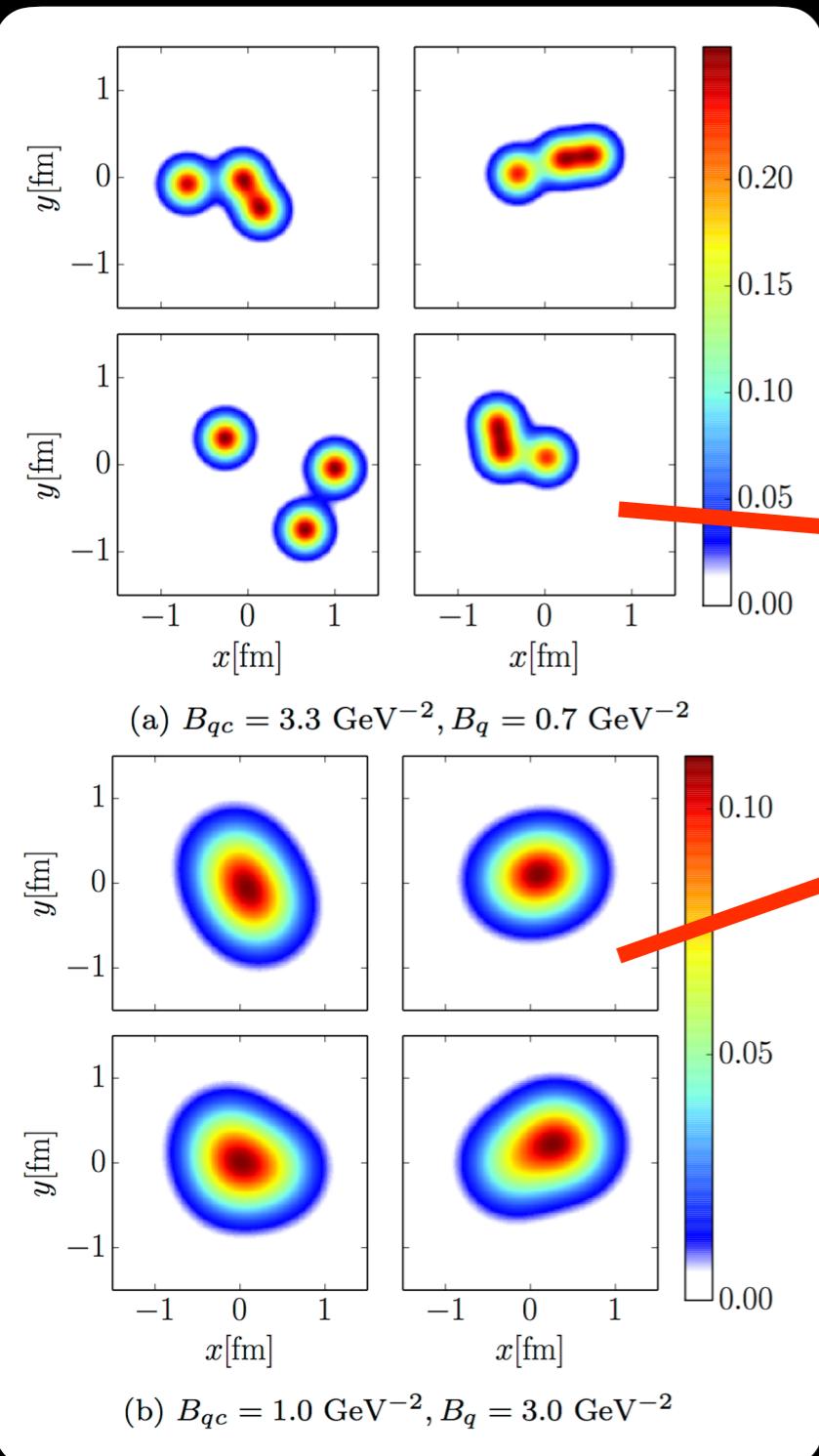
IMPLEMENTING GEOMETRIC FLUCTUATIONS OF THE TARGET

H. MÄNTYSAARI, B. SCHENKE, PHYS. REV. LETT. 117, 052301 (2016)
AND PHYS. REV. D94, 034042 (2016)

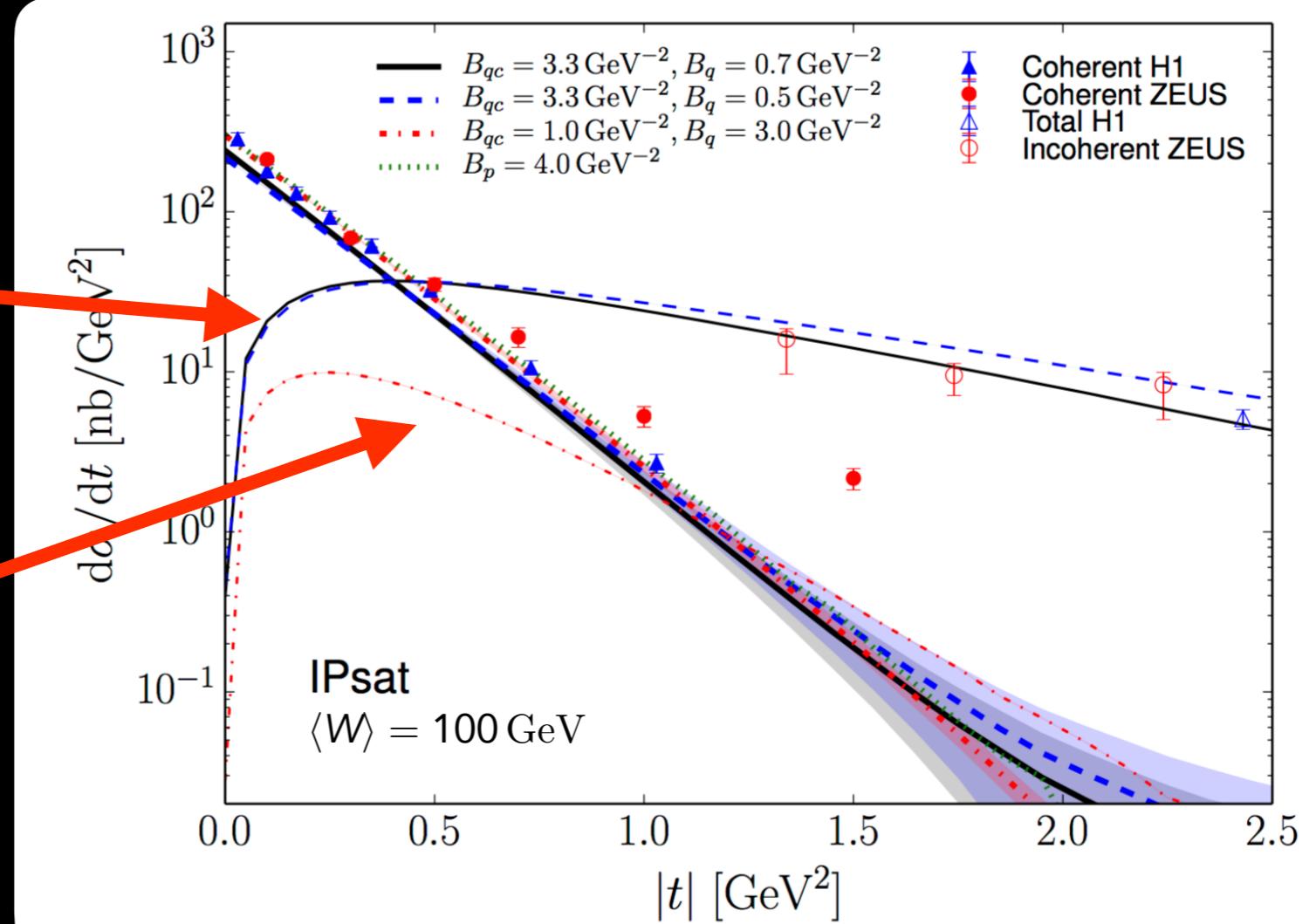
Use a simple constituent quark inspired model first

- Sample quark positions from a Gaussian distribution (width B_{qc})
- Small- x gluons are located around the valence quarks (Gaussian with width B_q)
- Combination of B_{qc} and B_q sets the degree of geometric fluctuations
- Dipole-target scattering: IPsat model fitted to F_2

EXCLUSIVE J/Ψ PHOTO-PRODUCTION



H. MÄNTYSAARI, B. SCHENKE,
 PHYS. REV. LETT. 117, 052301 (2016)
 AND PHYS. REV. D94, 034042 (2016)

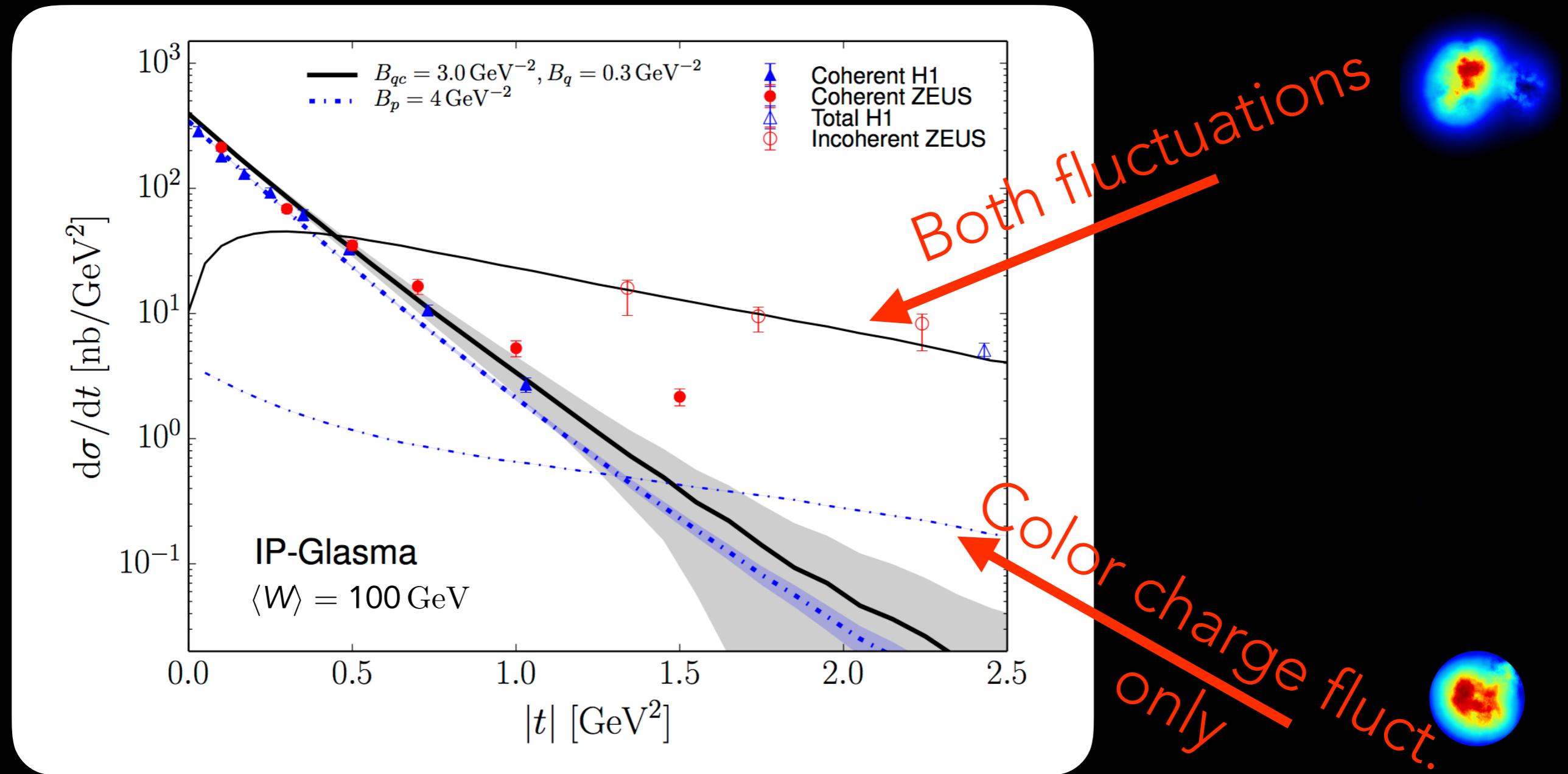


H1 COLLABORATION, EUR. PHYS. J. C46 (2006) 585,
 PHYS. LETT. B568 (2003) 205
 ZEUS COLLABORATION, EUR. PHYS. J. C24 (2002) 345
 EUR. PHYS. J. C26 (2003) 389

ADDING COLOR CHARGE FLUCTUATIONS

H. MÄNTYSAARI, B. SCHENKE, PHYS. REV. LETT. 117, 052301 (2016)
AND PHYS. REV. D94, 034042 (2016)

IPSat → IP-Glasma: 2D Yang-Mills picture of proton

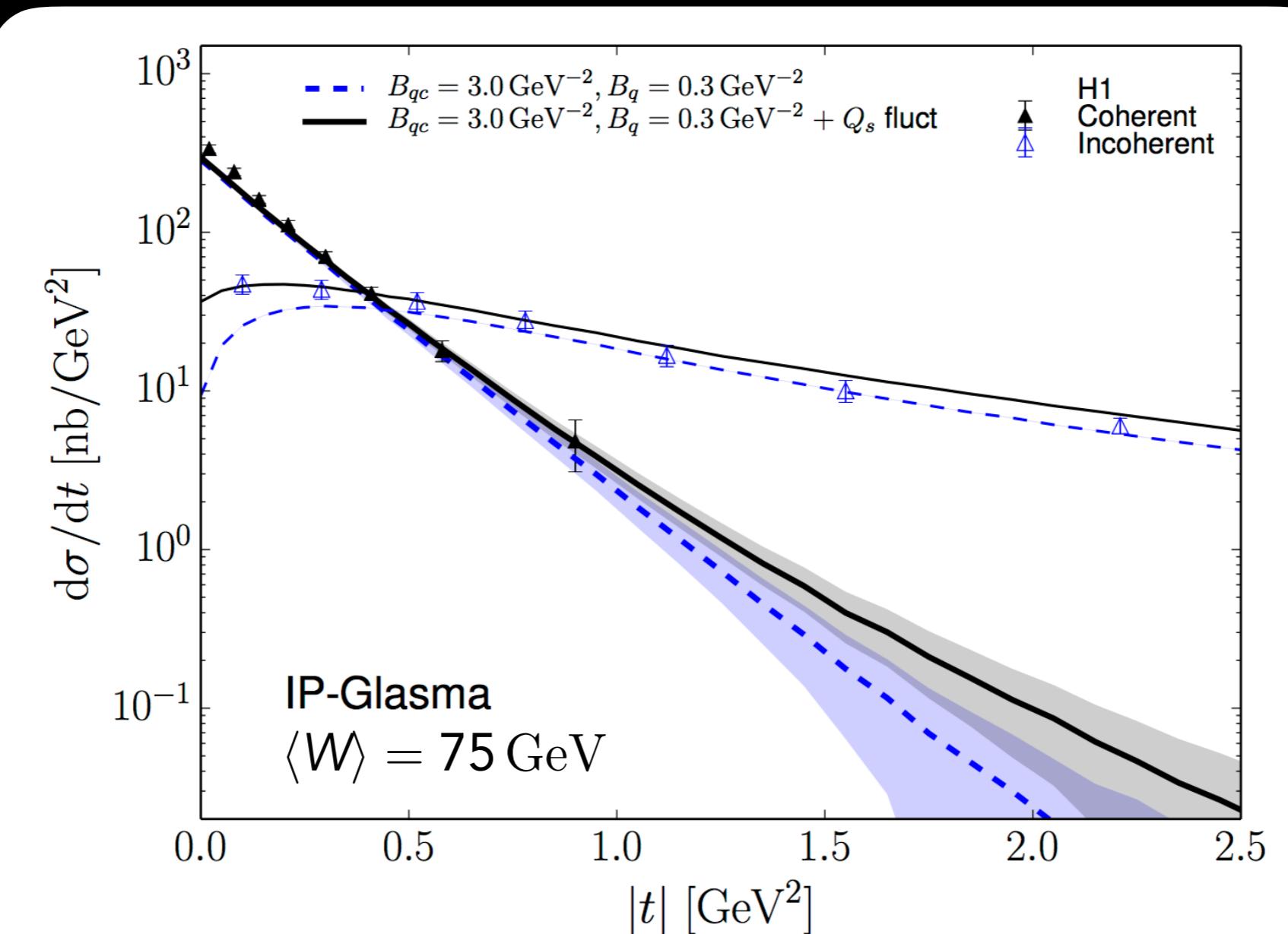


H1 COLLABORATION, EUR. PHYS. J. C46 (2006) 585, PHYS. LETT. B568 (2003) 205
ZEUS COLLABORATION, EUR. PHYS. J. C24 (2002) 345, EUR. PHYS. J. C26 (2003) 389

ADDING Q_S FLUCTUATIONS

H. MÄNTYSAARI, B. SCHENKE, PHYS. REV. LETT. 117, 052301 (2016)
AND PHYS. REV. D94, 034042 (2016)

|P-Glasma with Q_S fluctuations

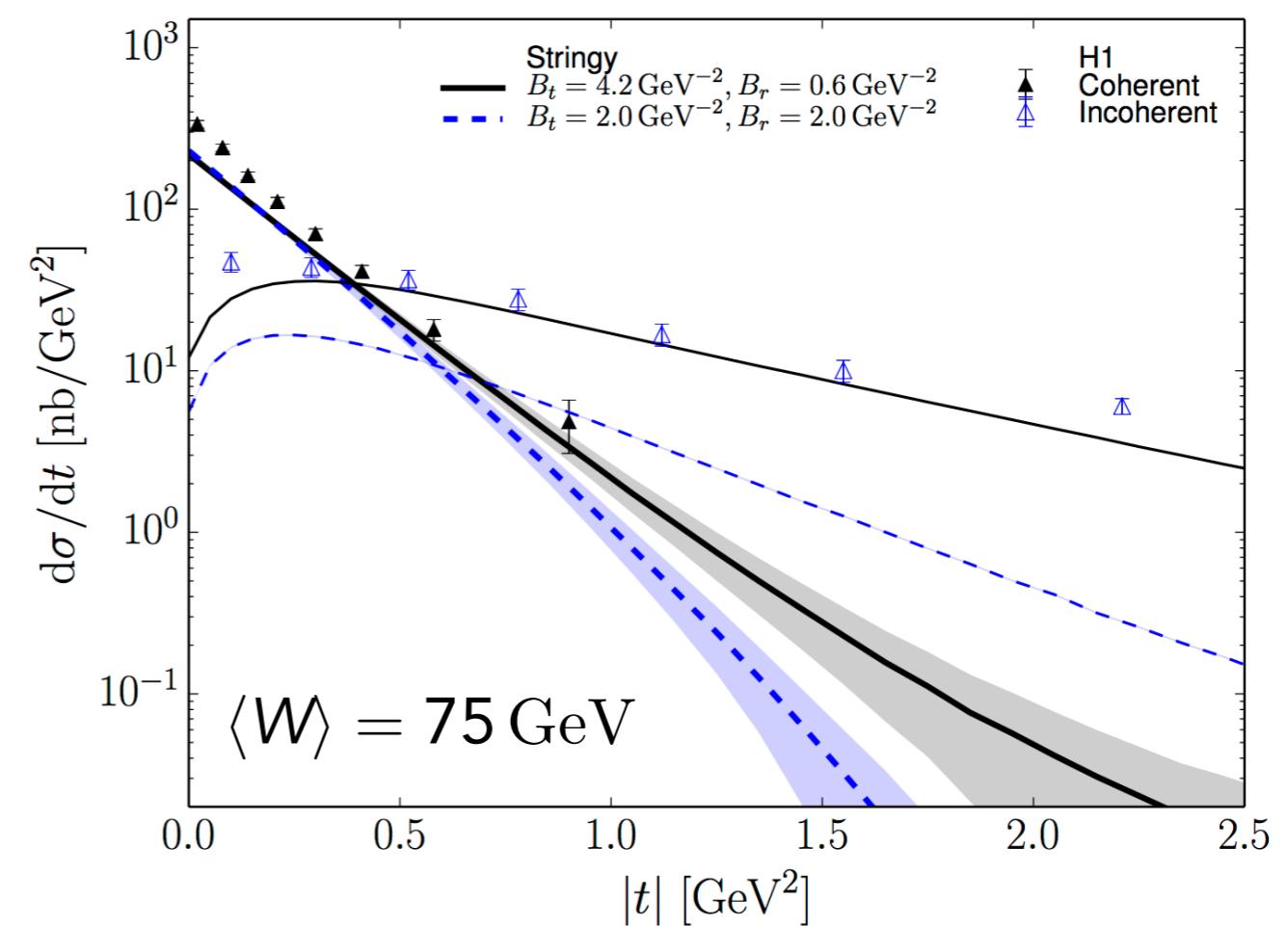
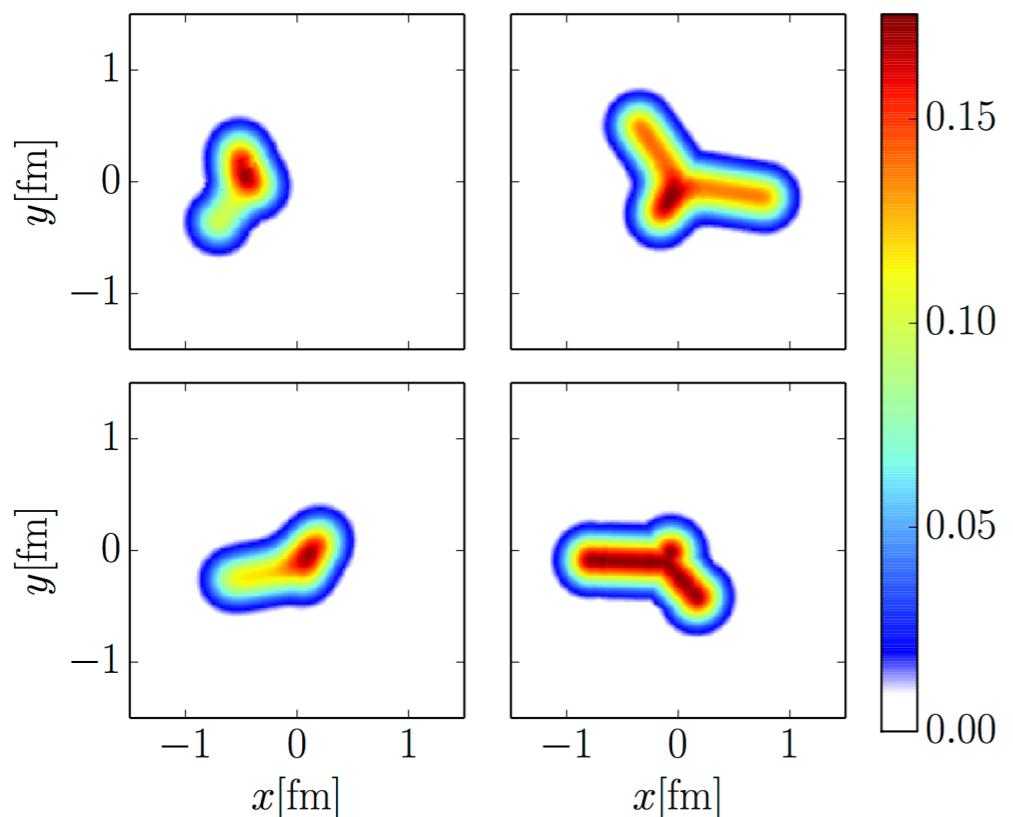


EXPERIMENTAL DATA: H1 COLLABORATION, JHEP 1005 (2010) 032

ALTERNATIVE MODELS

H. MÄNTYSAARI, B. SCHENKE, PHYS. REV. D94, 034042 (2016)

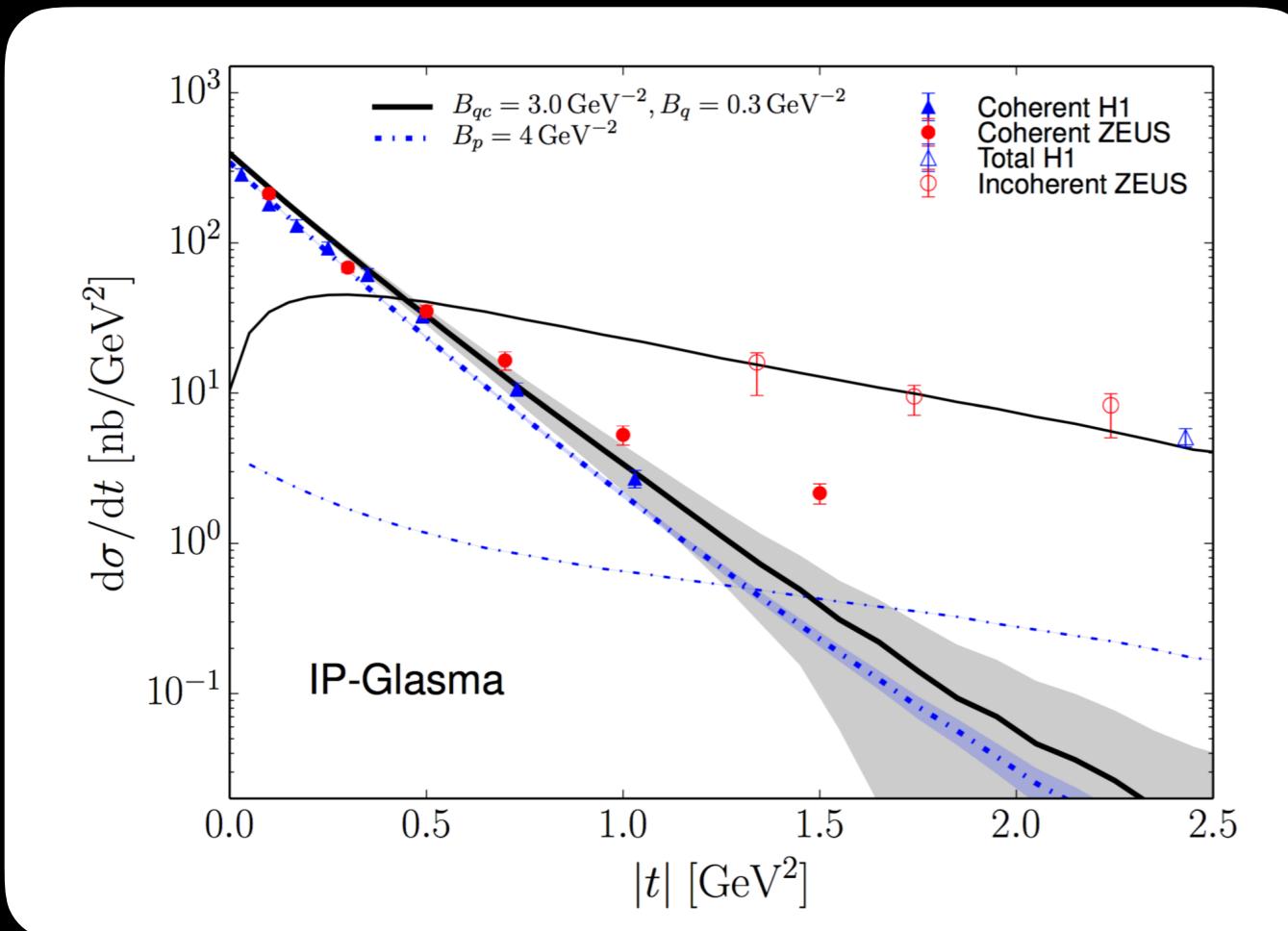
Stringy proton model gives similarly good agreement



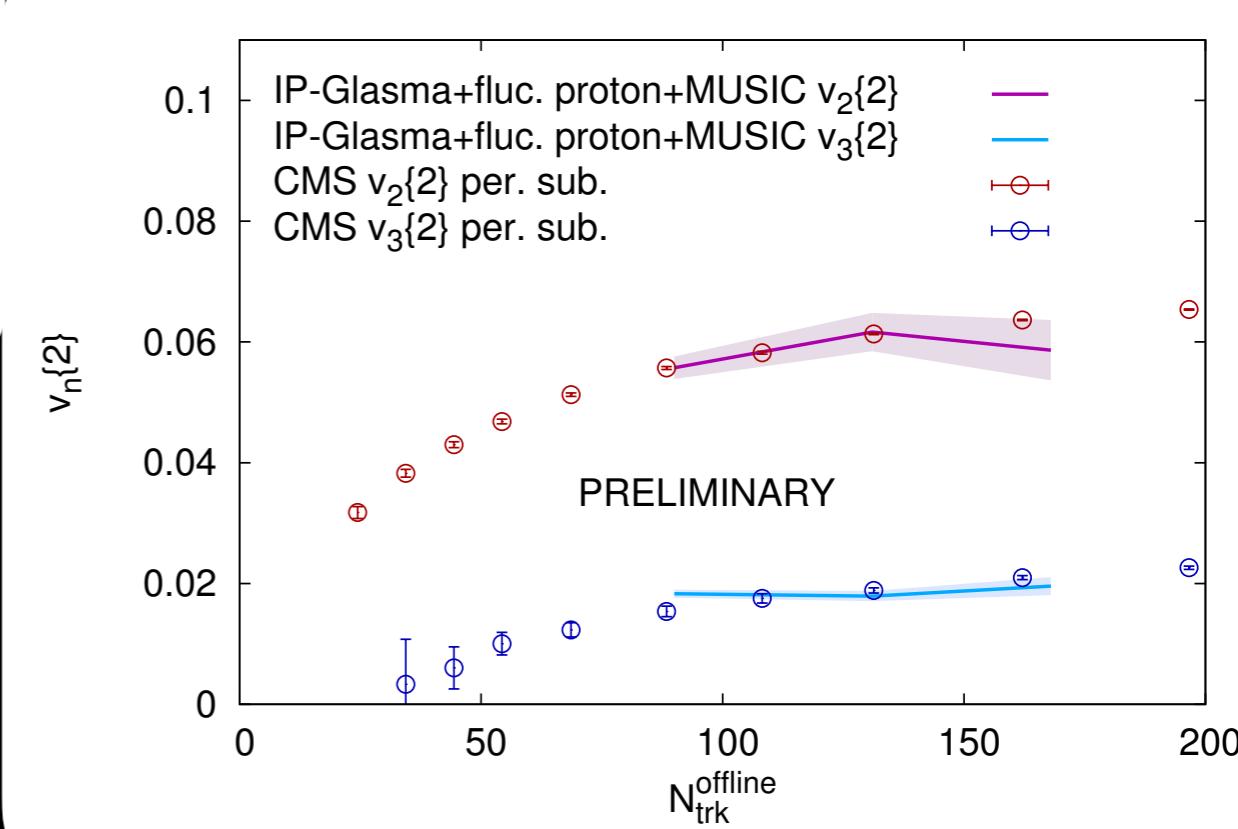
Cannot distinguish details between geometry models
but can determine degree of fluctuations

STRATEGY: CONSTRAIN PROTON FLUCTUATIONS WITH J/Ψ PRODUCTION AND PREDICT FLOW IN p+Pb COLLISIONS

H. MÄNTYSAARI, P. TRIBEDY, B. SCHENKE, IN PREPARATION



Use constrained proton
to predict v_n in p+Pb collisions



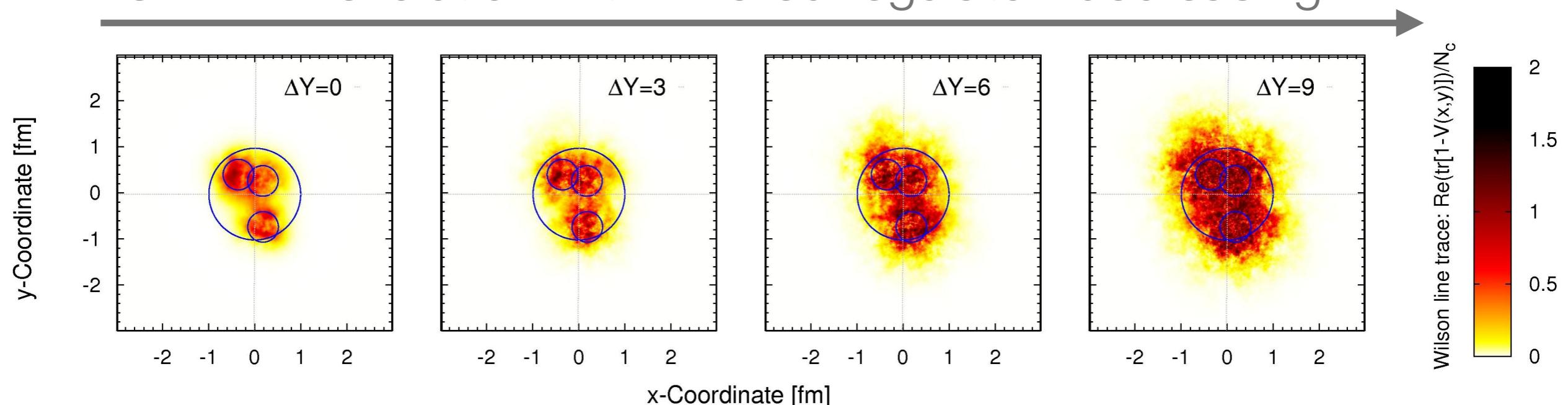
NEXT STEPS

H. MÄNTYSAARI, B. SCHENKE, IN PREPARATION

Implement energy evolution - predict cross sections at varying W
Study UPCs at LHC and EIC scenarios

S. SCHLICHTING, B. SCHENKE, PHYS. LETT. B739, 313-319 (2014)

JIMWLK evolution with infrared regulator: decreasing x



Hadron radius grows linearly with rapidity - "Gribov diffusion"
Even at small x the proton is not a sphere of gluons

WHAT AN EIC CAN ADD

- High luminosity and a detailed scan in x and Q^2
- Detailed measurements of different vector mesons
- Better discrimination of coherent and incoherent processes
- Scan in A : How does fluctuating gluon distribution change when going to light and to heavy ions
- Measure angular correlations of scattered electron and produced vector meson (or to proton spin?):
Determine harmonics of proton shape fluctuations:
eccentricity, triangularity, etc.
- Precision imaging of the fluctuating proton shape

SUMMARY



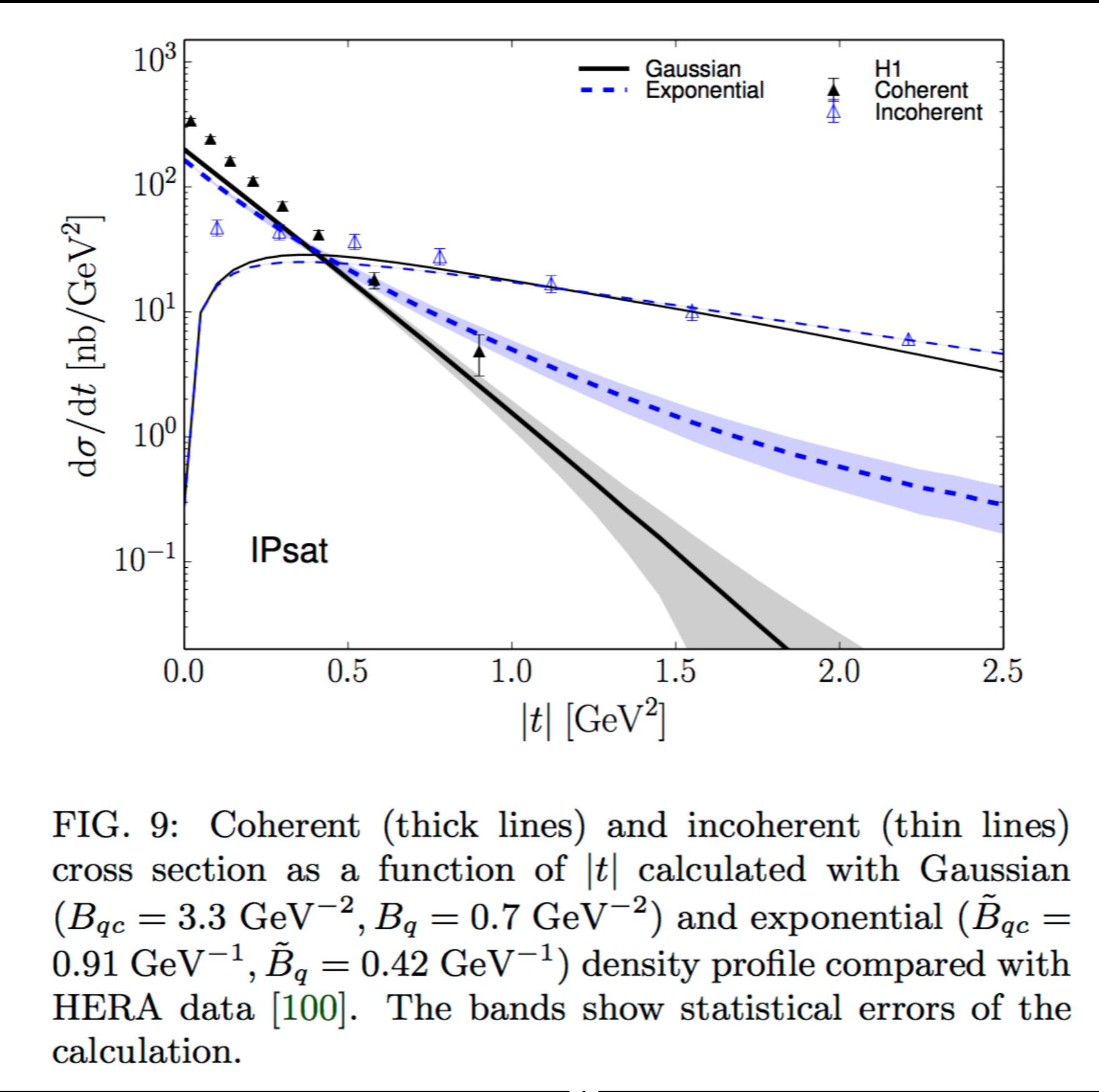
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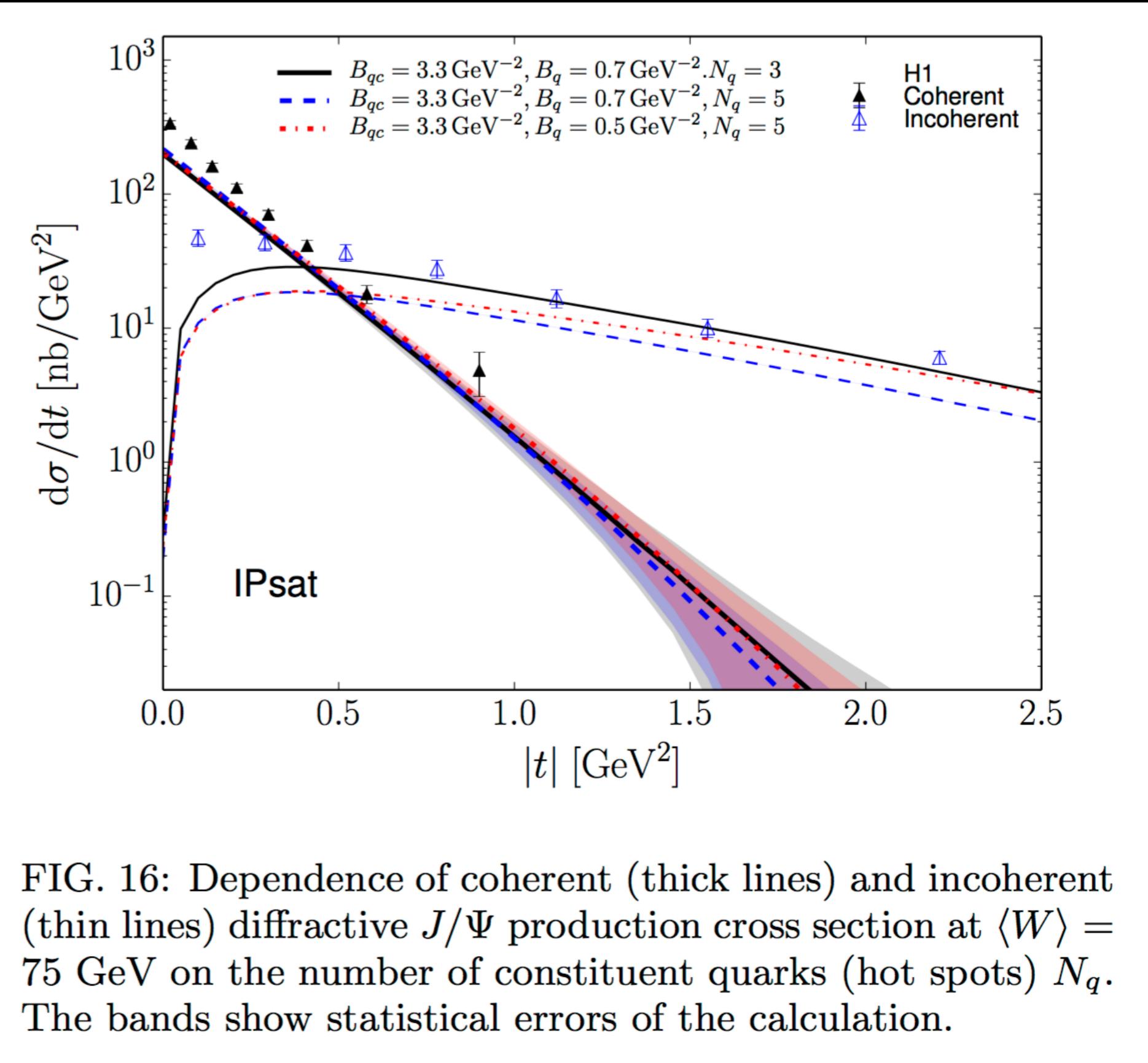
- Incoherent diffraction is highly sensitive to proton shape fluctuations
- Comparison to HERA data provides evidence for strong geometric fluctuations
- This is of fundamental interest
- It is also crucial for understanding the physics of high multiplicity p+A collisions
- A future EIC can provide even deeper insight into the fluctuating gluon distribution in the proton and nuclei

BACKUP

EXPONENTIAL DISTRIBUTION

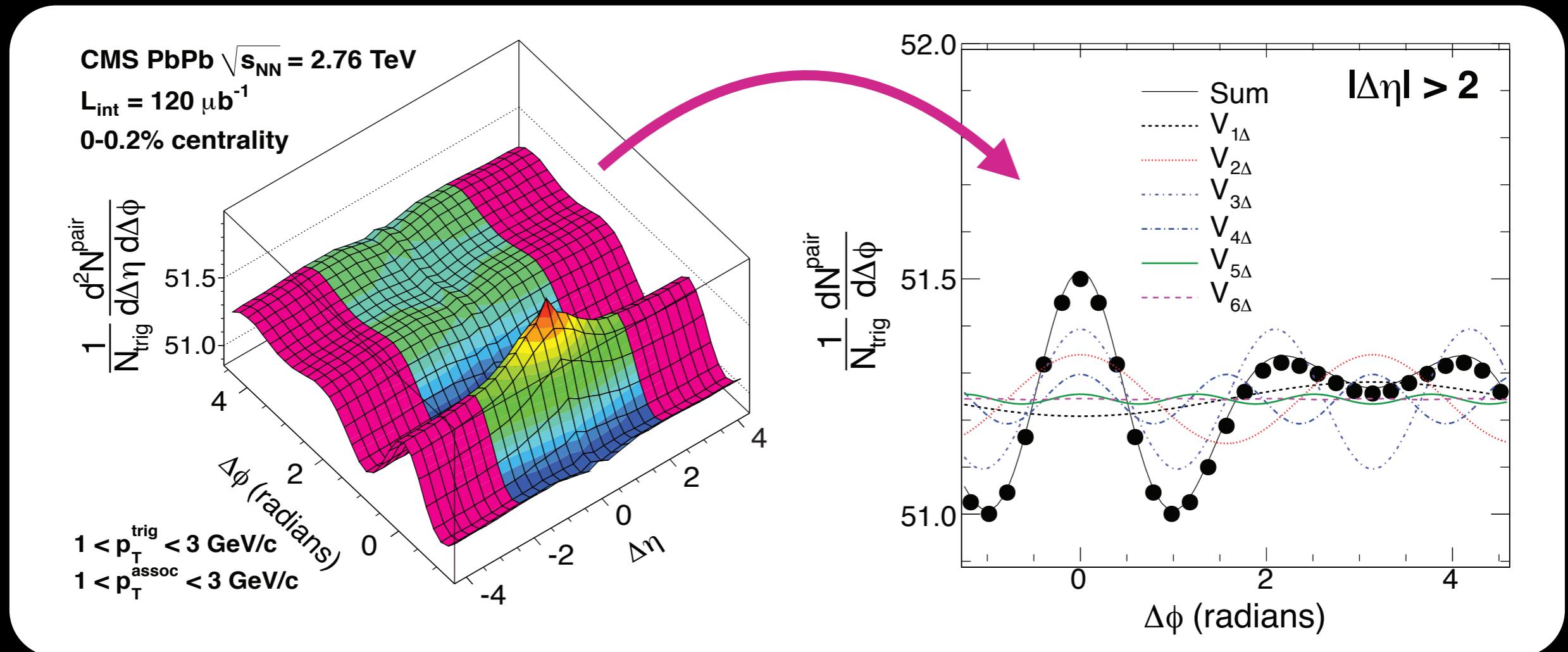


NUMBER OF 'HOT-SPOTS'



FOURIER EXPANSION

Azimuthal structure quantified using Fourier expansion

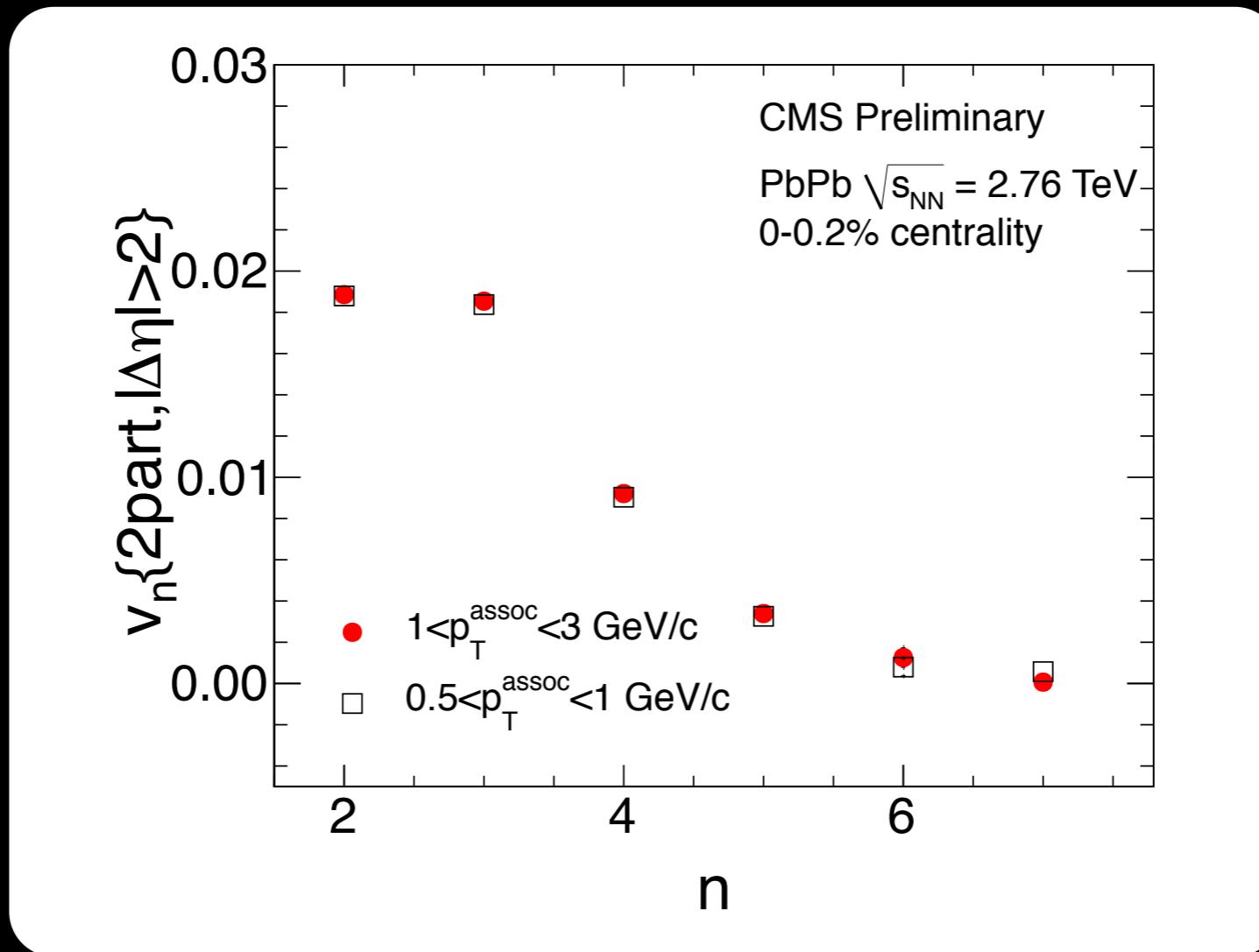


$$\frac{1}{N_{\text{trig}}} \frac{dN_{\text{pair}}}{d\Delta\phi} \sim 1 + 2 \sum_{n=1}^{n=\infty} V_{n\Delta}(p_T^{\text{trig}}, p_T^{\text{assoc}}) \cos(n\Delta\phi) \quad v_n = \sqrt{V_{n\Delta}}$$

FOURIER SPECTRUM

Azimuthal structure quantified using Fourier expansion

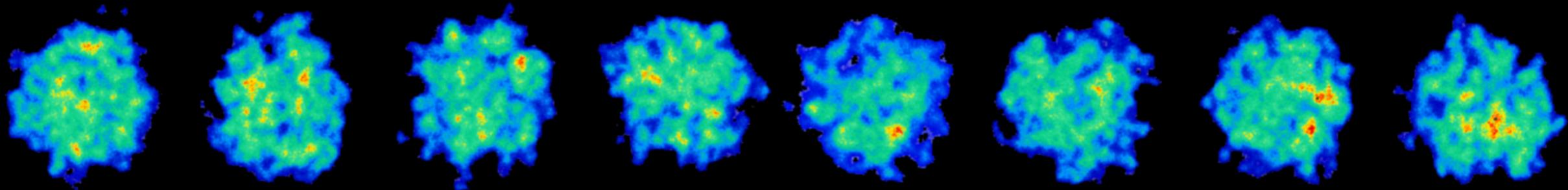
V_n



$$\frac{1}{N_{\text{trig}}} \frac{dN^{\text{pair}}}{d\Delta\phi} \sim 1 + 2 \sum_{n=1}^{n=\infty} V_{n\Delta}(p_T^{\text{trig}}, p_T^{\text{assoc}}) \cos(n\Delta\phi) \quad v_n = \sqrt{V_{n\Delta}}$$

THEORETICAL DESCRIPTION IN HEAVY IONS

FLUCTUATING NUCLEON POSITIONS AND COLOR CHARGES
→ FLUCTUATING DEPOSITED ENERGY

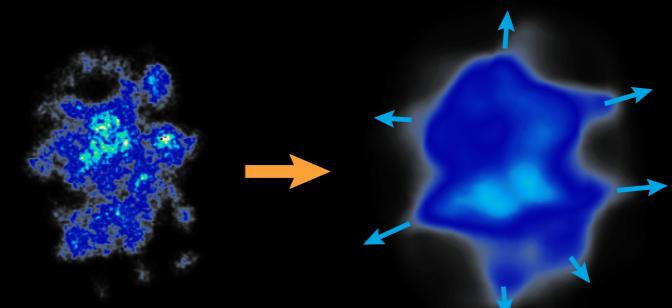


HIGH ENERGY: INITIAL FLUCTUATING ENERGY DENSITY CAN BE COMPUTED IN THE CGC FRAMEWORK (IP-GLASMA MODEL)

B.SCHENKE, P.TRIBEDY, R.VENUGOPALAN, PRL108, 252301 (2012), PRC86, 034908 (2012)

PRESSURE GRADIENTS DRIVE THE EVOLUTION
DESCRIBED BY HYDRODYNAMICS
FIELD WAS LARGELY DRIVEN BY ULI'S WORK:

- P. F. KOLB, J. SOLLFRANK, U. W. HEINZ, PHYS.REV. C62 (2000) 054909
P. F. KOLB, P. HUOVINEN, U. W. HEINZ, H. HEISELBERG, PHYS.LETT. B500 (2001) 232-240
H. SONG, U. W. HEINZ, J.PHYS. G36 (2009) 064033
H. SONG, S. A. BASS, U. HEINZ, T. HIRANO, C. SHEN, PHYS.REV.LETT. 106 (2011) 192301
...



IP-GLASMA INITIAL CONDITION + MUSIC

C.GALE, S.JEON, B.SCHENKE, P.TRIBEDY, R.VENUGOPALAN, PRL110, 012302 (2013)